H-Block Compatibility Analysis for GSM, UMTS and LTE

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Executive Summary

In FCC Docket 12-357, the Commission has proposed rules for the Advanced Wireless Services (AWS) H Block that would make available ten megahertz of spectrum for flexible use and would extend the widely deployed PCS band. The upper limit of the mobile device uplink for this proposed block is only 10 MHz away from the lower limit of the existing PCS A Block downlink. As a result of this close duplex gap, there is a potential for interference to legacy PCS devices from H Block devices through three mechanisms:

- Receiver blocking of A Block GSM, UMTS and LTE devices
- Third-order intermodulation interference (2*1917.5 MHz-1877.5 MHz) to B Block UMTS and LTE devices
- Out of Band Emission (OOBE) interference to A Block GSM, UMTS and LTE devices

Devices operating on one of three potentially affected airlinks (GSM, UMTS and LTE) were studied, under laboratory conditions, for their susceptibility to receive performance impairment when in close proximity to an emulated LTE device operating in the proposed H Block. The H Block device was assumed to be operating at a maximum power of +23 dBm (± 2dB) into an antenna with a gain of 0 dBi. The victim device was also assumed to have an antenna gain of 0 dBi, and the victim device was assumed to be 1 meter away from the H Block device. In addition, the H Block device was assumed to comply with an emission mask which calls for a maximum out-of-band emissions level of -66 dBm/MHz (-126 dBm/Hz) measured at the H Block device's antenna feedpoint across the frequency band covering 1930-2000 MHz.

The results of our laboratory analysis are summarized as follows:

PCS A Block Interference Due to Blocking/Overload:

All three airlink technologies displayed reasonable immunity to blocking and/or overload from an emulated H Block device based on the assumptions above, with GSM showing the most noticeable impairment under favorable downlink signal conditions (serving cell 3 dB above the 3GPP-specified sensitivity). UMTS devices displayed good immunity to a nearby H Block device, but UMTS devices may display compromised immunity (similar to that of GSM devices) when the serving network is heavily loaded. LTE performance at low signal levels appears to be almost identical to that of UMTS devices operating in a lightly-loaded network. Overall, receiver blocking/overload should not present a significant problem for UMTS and LTE devices according to the assumptions above. GSM devices display noticeable performance impairment when the H block device transmits at a power level within 2 dB from its nominal maximum output power of 23 dBm. These test results indicate that the coexistence latitude for blocking/overload of GSM devices is very limited.

PCS B Block Interference Due to Intermodulation Distortion

This test only applies to UMTS and LTE devices. No B Block performance impairment was noted in devices supporting either airlink technology under the test conditions described above until the device was exposed to very high H Block signal levels.

PCS A Block Interference Due to H Block Out of Band Emissions

The results of this test showed the greatest differences between airlink technologies. UMTS and LTE displayed good immunity to wideband noise emissions from a nearby H Block transmitter based on the assumed out-of-band emissions (OOBE) limit stipulated in the introduction of this section (-66 dBm/MHz) and a separation distance of 1 meter. However, both GSM devices displayed relatively poor rejection of OOBE interference. Our data show that GSM devices are more susceptible to OOBE from a nearby H Block device than UMTS and LTE devices by a factor of about 7 to 10 dB.

In general, it appears that an H Block power limit of +23 dB (±2 dB) and an out of band emissions limit of -66 dBm/1 MHz between 1930 and 2000 MHz will be sufficient to ensure reasonable coexistence between LTE devices operating in the FCC's proposed H Block and legacy UMTS and LTE devices operating in the PCS A and B Blocks. However, GSM devices display moderate performance impairment in the presence of an H Block device at a separation of 1 meter due to receiver blocking when the H block device transmits at near maximum output power. GSM devices are also more susceptible to OOBE from a nearby H Block device than UMTS and LTE devices by a factor of about 7 to 10 dB, therefore may have very little latitude for coexistence with an H Block device at a separation of 1 meter.

Details of the tests executed to compile this summary are described in the sections that follow.

Introduction

Initially, the 1900 MHz PCS allocation (Blocks A through F) was designed in such a manner as to maintain a 20 MHz duplex gap between the highest mobile transmit frequency and the lowest mobile receive frequency. The FCC's recent proposal to add an H Block (WT Docket No 12-357) would reduce the 1900 MHz PCS duplex gap to only 10 MHz.

Because of this narrow duplex gap, AT&T and T-Mobile USA believed that it was important to investigate the potential interference that could occur between devices operating in the proposed H Block and existing devices currently operating in the PCS band. Therefore, a test methodology was prepared to evaluate, under laboratory conditions, the interference potential between H Block LTE devices and GSM, UMTS and LTE devices operating in the PCS A or B blocks.

This test methodology was focused on:

- Receiver blocking of A Block GSM, UMTS and LTE UEs while emulating an H Block LTE UE in close physical proximity
- Third-order intermodulation interference (2*1917.5 MHz-1877.5 MHz) to B Block UMTS and LTE UEs while emulating an H Block LTE UE in close physical proximity
- Out of Band Emission (OOBE) interference to A Block GSM, UMTS and LTE devices while emulating an H Block LTE UE in close physical proximity

Discussion

When executing tests to evaluate potential interference, there are two general approaches which can be used:

Worst Case Testing: When evaluating interference susceptibility of a device under worst-case conditions, the specific test points are based on the selected device’s actual sensitivity as opposed to the sensitivity required by industry conformance testing (e.g. 3GPP). In some cases, the delta between the device’s actual sensitivity and the 3GPP sensitivity can be considerable (7 to 10 dB is not uncommon). The primary advantage to worst-case testing is that it allows carriers to understand the interference susceptibility associated with new allocation proposals when the selected device is verified to be operating at a pre-determined performance point (as opposed to a conformance point). This type of test environment may or may not be realistic, because it’s unlikely that the performance of the entire population of a given test device is the same as the single sample used for testing. Also, most radio link budgets are based on the 3GPP sensitivity and a 0 dBi antenna, so the device’s sensitivity beyond that required by the specification extends the calculated link budget on a per-device basis. Finally, it’s difficult to compare measurements between devices under worst-case test conditions, because the reference sensitivity of each test device is typically different (in some cases, the differences in sensitivity are significant).

Typical Design Testing: When testing a device under typical design conditions, the tests are based on the 3GPP-specified sensitivity rather than the actual reference sensitivity of the UE receiver. The primary advantage to this approach is that all devices, regardless of how well they individually perform relative to the 3GPP spec, are tested in exactly the same environment. Thus, it’s possible to directly compare the susceptibility of Device A to that of Device B, etc., without any need to compensate for individual device performance. Also, many radio link budgets are based on the 3GPP-specified sensitivity and a 0 dBi antenna gain. The disadvantage to this approach is that we utilize an operating point that is probably well above the device’s actual sensitivity. Thus, a stronger interfering signal is required to realize impairment in performance.

The H Block tests executed by 7 Layers (in accordance with test plans agreed to by AT&T and T-Mobile USA) include both conditions above. Initially, all testing was limited to the “typical design” scenario, primarily because of the advantages listed above. However, we subsequently learned that Sprint (and later Verizon Wireless) utilized the “worst-case” approach, which meant that their tests would render results which could differ considerably from ours, especially in cases where the device is tested at its 1 dB desense point[1]. This would make comparison of test results difficult.

As a response to the test approach taken by Sprint and Verizon Wireless, AT&T and T-Mobile USA modified their test plan to utilize the test device’s actual reference sensitivity as the reference point. The operating points in this new test plan were now set to UE REFSENS +1 dB and UE REFSENS +3 dB for all Radio Access Technologies (RATs), as opposed to 3GPP REFSENS +3 for GSM/UMTS and 3GPP REFSENS +6 dB for LTE. However, only a small subset of devices was tested using the “worst-case” test approach, primarily because of time and budget considerations.

Finally, it’s important to note that interference susceptibility tests executed against UMTS devices should include an operating environment which emulates lightly-loaded and heavily-loaded cell conditions. For example, almost all 3GPP tests utilize a traffic channel power that’s considered typical for a lightly-loaded cell. As a UMTS cell picks up users, the power allocated to each user in the downlink is reduced and the noise-rise in the uplink is increased. The net effect is that the signal-to-noise ratio for each user-link is reduced in both downlink and uplink. Hence the effective coverage of the cell on a per-user basis is reduced as well (this effect is typically known as “cell breathing”).

As our results show, the effects of cell-breathing can be significant, especially for cases where the device was tested in the “worst case” environment. In the tables that follow, a lightly-loaded UMTS cell is defined as one with a *DPCH_Ec/Ior* of -10.3 dB. All 3GPP reference sensitivity tests are executed at this traffic channel power offset. For the purpose of this test effort, a heavily-loaded UMTS cell has been defined as providing a *DPCH_Ec/Ior* of -16.6 dB. Because the traffic channel power offset has been increased about 6 dB in the heavily-loaded cell scenario, tests executed using the “worst-case” test methodology will display a high residual BER, especially in cases where *Ior* is only 1 dB above the UE’s actual reference sensitivity. Thus, the heavily-loaded cell scenarios are most useful when testing under “typical design” conditions. However, the loaded-cell test condition was included in the worst-case test environment for completeness.

[1] The 1 dB desense point was used by AT&T/T-Mobile USA only because this is one of two operating points utilized in the filings from Sprint and Verizon Wireless. It is not typically used during conformance or performance testing, primarily because the measurement uncertainty associated with it is rather high. The measurement metric (throughput or BER/FER) displays highly non-linear behavior as the downlink signal power approaches the device’s actual reference sensitivity, an effect which makes up a large part of the measurement uncertainty. VCOMM noted unexplained performance differences at 1 dB desense that were not observed at 3 dB desense, and it’s likely that these differences are due, in large part, to non-linear receiver behavior as the serving cell power approaches the device’s reference sensitivity.

Receiver Blocking/Overload Test Results

Worst-Case Test Conditions

Tests in this section were executed at a serving cell downlink power level either 1 dB or 3 dB above the device's actual reference sensitivity.

Table 1.1, UMTS Device Performance for A Block Receiver Blocking/Overload, Worst Case, 1 dB Desense

Band II PCS A Block UMTS Receiver Blocking Test, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 5 RB LTE H-Block Interferer, 1 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -10.3 dB, 25 RB LTE H-Block Interferer 1 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 5 RB LTE H-Block Interferer 1 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 25 RB LTE H-Block Interferer 1 dB Desense from Device Sensitivity
UMTS Device A	-14 dBm	-10 dBm	BER Not Met	BER Not Met
UMTS Device C	-50 dBm	-46 dBm	BER Not Met	BER Not Met

Table 1.2, LTE Device Performance for A Block Receiver Blocking/Overload, Worst-Case, 1 dB Desense

Band 2, PCS A Block LTE Receiver Blocking Test, Worst Case	5 RB LTE H-Block Interferer, 1 dB Desense from Device Sensitivity	25 RB LTE H-Block Interferer, 1 dB Desense from Device Sensitivity
LTE Device A	-14 dBm	-9 dBm

Table 1.3, UMTS Device Performance for A Block Receiver Blocking/Overload, Worst Case, 3 dB Desense

Band II PCS A Block UMTS Receiver Blocking Test, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 5 RB LTE H-Block Interferer, 3 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -10.3 dB, 25 RB LTE H-Block Interferer 3 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 5 RB LTE H-Block Interferer 3 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 25 RB LTE H-Block Interferer 3 dB Desense from Device Sensitivity
UMTS Device A	-10 dBm	-6 dBm	BER Not Met	BER Not Met
UMTS Device C	-15 dBm	-12 dBm	BER Not Met	BER Not Met

Table 1.4, LTE Device Performance for A Block Receiver Blocking/Overload, Worst-Case, 3 dB Desense

Band 2 PCS A Block LTE Receiver Blocking Test, Worst Case	5 RB LTE H-Block Interferer, 3 dB Desense from Device Sensitivity	25 RB LTE H-Block Interferer, 3 dB Desense from Device Sensitivity
LTE Device A	-9 dBm	-6 dBm

Typical Design Test Conditions, Receiver Blocking/Overload

Tests in this section were executed at a serving cell downlink power level either 3 dB or 6 dB above the 3GPP reference sensitivity specified for the RAT under test.

Table 2.1, GSM Device Performance for A Block Receiver Blocking/Overload, Typical Design Conditions, 3 dB Desense

PCS A Block GSM Receiver Blocking Test, Typical Design Case	5 RB LTE H-Block Interferer, 3dB Desense from 3GPP Sensitivity	25 RB LTE H-Block Interferer, 3 dB Desense from 3GPP Sensitivity
GSM Device A	-12.3 dBm	-15 dBm
GSM Device B	-16.9 dBm	-17 dBm

Table 2.2, UMTS Device Performance for A Block Receiver Blocking/Overload, Typical Design Conditions, 3 dB Desense

PCS A Block UMTS Receiver Blocking Test, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 5 RB LTE H-Block Interferer, 1 dB Desense from 3GPP Sensitivity	*DPCH_Ec/Ior* of -10.3 dB, 25 RB LTE H-Block Interferer 1 dB Desense from 3GPP Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 5 RB LTE H-Block Interferer 1 dB Desense from 3GPP Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 25 RB LTE H-Block Interferer 1 dB Desense from 3GPP Sensitivity
UMTS Device B	-2.25 dBm	-1.35 dBm	-11.35 dBm	-9.65 dBm
UMTS Device C	-10.05 dBm	-9.15 dBm	-17.85 dBm	-14.35 dBm

Table 2.3, LTE Device Performance for A Block Receiver Blocking/Overload, Typical Design Case, 6dB Desense

Band 2, PCS A Block LTE Receiver Blocking Test, Typical Design Case	5 RB LTE H-Block Interferer, 6 dB Desense from 3GPP Sensitivity	25 RB LTE H-Block Interferer, 6 dB Desense from 3GPP Sensitivity
LTE Device A	-9.6 dBm	-4.0 dBm

Receiver IMD

Worst-Case Test Conditions

Tests in this section were executed at a serving cell downlink power level either 1 dB or 3 dB above the device's actual reference sensitivity.

Table 3.1, UMTS Device Performance for B Block Receiver IMD, Worst Case, 1 dB Desense

Band II PCS B Block UMTS Receiver IMD Test, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 5 RB LTE H-Block Interferer, 1 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -10.3 dB, 25 RB LTE H-Block Interferer 1 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 5 RB LTE H-Block Interferer 1 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 25 RB LTE H-Block Interferer 1 dB Desense from Device Sensitivity
UMTS Device A	-12 dBm	-11 dBm	BER Not Met	BER Not Met
UMTS Device C	-15 dBm	-13 dBm	BER Not Met	BER Not Met

Table 3.2, LTE Device Performance for B Block Receiver IMD, Worst-Case, 1 dB Desense

Band 2, PCS B Block LTE Receiver IMD Test, Worst Case	5 RB LTE H-Block Interferer, 1 dB Desense from Device Sensitivity	25 RB LTE H-Block Interferer, 1 dB Desense from Device Sensitivity
LTE Device A	-3 dBm	-3 dBm

Table 3.3, UMTS Device Performance for B Block Receiver IMD, Worst Case, 3 dB Desense

PCS B Block UMTS Receiver Blocking Test, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 5 RB LTE H-Block Interferer, 3 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -10.3 dB, 25 RB LTE H-Block Interferer, 3 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 5 RB LTE H-Block Interferer 3 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 25 RB LTE H-Block Interferer 3 dB Desense from Device Sensitivity
UMTS Device A	-14 dBm	-10 dBm	-33 dBm	-42 dBm
UMTS Device C	-14 dBm	-12 dBm	BER Not Met	BER Not Met

Table 3.4, LTE Device Performance for B Block Receiver Blocking/Overload, Worst-Case, 3 dB Desense

PCSB Block LTE Receiver Blocking Test, Worst Case	5 RB LTE H-Block Interferer, 3 dB Desense from Device Sensitivity	25 RB LTE H-Block Interferer, 3 dB Desense from Device Sensitivity
LTE Device A	-1 dBm	0 dBm

Typical Design Test Conditions, Receiver IMD

Tests in this section were executed at a serving cell downlink power level either 3 dB or 6 dB above the 3GPP reference sensitivity specified for the RAT under test.

Table 4.1, UMTS Device Performance for B Block Receiver IMD, Typical Design Conditions, 3 dB Desense

PCS B Block UMTS Receiver IMD Test, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 5 RB LTE H-Block Interferer, 3 dB Desense from 3GPP Sensitivity	*DPCH_Ec/Ior* of -10.3 dB, 25 RB LTE H-Block Interferer, 3dB Desense from 3GPP Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 5 RB LTE H-Block Interferer, 3 dB Desense from 3GPP Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 25 RB LTE H-Block Interferer, 3 dB Desense from 3GPPSensitivity
UMTS Device B	-2.05 dBm	-1.25 dBm	-9.65 dBm	-6.75 dBm
UMTS Device C	-10.95 dBm	-9.45 dBm	-17.05 dBm	-15.85 dBm

Table 4.2, LTE Device Performance for B Block Receiver IMD, Typical Design Case, 6dB Desense

Band 2, PCS B Block LTE Receiver IMD Test, Typical Design Case	5 RB LTE H-Block Interferer, 6 dB Desense from 3GPP Sensitivity	25 RB LTE H-Block Interferer 6 dB Desense from 3GPP Sensitivity
LTE Device A	-7.5 dBm	-6.0 dBm

Receiver Susceptibility to H Block OOBE Test Results

Worst-Case Test Conditions

Tests in this section were executed at a serving cell downlink power level either 1 dB or 3 dB above the device's actual reference sensitivity.

Table 5.1, GSM Device Performance for A Block Receiver OOBE Susceptibility, Worst-Case, 1 dB Desense

PCS A Block GSM Receiver OOBE Susceptibility, Worst Case	1dB Desense from Device Sensitivity
GSM Device A	-174 dBm/Hz
GSM Device B	-177 dBm/Hz

Table 5.2, UMTS Device Performance for A Block Receiver OOBE Susceptibility, Worst Case, 1 dB Desense

PCS A Block UMTS Receiver OOBE Susceptibility, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 1 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 1 dB Desense from Device Sensitivity
UMTS Device A	-165 dBm/Hz	BER Not Met
UMTS Device C	-166 dBm/Hz	BER Not Met

Table 5.3, LTE Device Performance for A Block Receiver OOBE Susceptibility, Worst-Case, 1 dB Desense

Band 2, PCS A Block LTE Receiver OOBE Susceptibility, Worst Case	1 dB Desense from Device Sensitivity
LTE Device A	-166 dBm/Hz

Table 5.4, GSM Device Performance for A Block Receiver OOBE Susceptibility, Worst-Case, 3 dB Desense

PCS A Block GSM Receiver OOBE Susceptibility, Worst Case	3 dB Desense from Device Sensitivity
GSM Device A	-168 dBm/Hz
GSM Device B	-170 dBm/Hz

Table 5.5, UMTS Device Performance for A Block Receiver OOBE Susceptibility, Worst Case, 3 dB Desense

Band II PCS A Block UMTS Receive OOBE Susceptibility, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 3 dB Desense from Device Sensitivity	*DPCH_Ec/Ior* of -16.6 dB 3 dB Desense from Device Sensitivity
UMTS Device A	-162 dBm/Hz	BER Not Met
UMTS Device C	-161 dBm/Hz	BER Not Met

Table 5.6, LTE Device Performance for A Block Receiver OOBE Susceptibility, Worst-Case, 3 dB Desense

Band 2 PCS A Block LTE Receiver OOBE Susceptibility, Worst Case	3 dB Desense from Device Sensitivity
LTE Device A	-163 dBm/Hz

Typical Design Test Conditions

Tests in this section were executed at a serving cell downlink power level either 3 dB above the 3GPP reference sensitivity specified for the RAT under test.

Table 6.1, UMTS Device Performance for A Block OOBE Susceptibility, Typical Design Conditions, 3 dB Desense

PCS A Block UMTS Receiver OOBE Susceptibility, Worst Case	*DPCH_Ec/Ior* of -10.3 dB, 3 dB Desense from 3GPP Sensitivity	*DPCH_Ec/Ior* of -16.6 dB, 3 dB Desense from 3GPP Sensitivity
UMTS Device A	-154.9 dBm/Hz	-162.3 dBm/Hz
UMTS Device B	-155.7 dBm/Hz	-166.4 dBm/Hz
UMTS Device C	-155.7 dBm/Hz	-166.7 dBm/Hz

Table 6.2, LTE Device Performance for A Block Receiver OOBE Susceptibility, Typical Design Case, 3dB Desense

Band 2, PCS A Block LTE Receiver OOBE Susceptibility Typical Design Case	3 dB Desense from 3GPP Sensitivity
LTE Device A	-149 dBm/Hz

Test Result Analysis

Prerequisites

To analyze a device's sensitivity to any of the three impairment mechanisms that can come into play when a 1900 MHz PCS Block A or B device is in the presence of an LTE device operating in the proposed PCS H Block, we shall work from the following prerequisites:

1) The minimum separation between the H Block LTE transmitter and the A or B Block receiver is 1 meter
2) The free-space path loss at 1 meter is 38 dB at 1930 MHz
3) The LTE H-Block transmitter is operating at a maximum power of +23 dBm ± 2 dB
4) The LTE H Block device and the A or B Block victim device utilize omnidirectional antennas with a maximum gain of 0 dBi from 1850 to 2000 MHz
5) The LTE H Block transmitter complies with an out-of-band emissions (OOBE) limit of -66 dBm/MHz (-126 dBm/Hz) between 1930 and 2000 MHz at the H Block device's antenna feedpoint.

Based on the prerequisites above, the maximum H Block power that could appear at the A or B Block device's receiver at a distance of 1 meter is (+25 dBm-38 dB)=-13 dBm. In reality, the H Block device and the majority of victim devices is likely to have an antenna gain in the range of -1.5 to -3 dB at 1930 MHz, so if we assume a relatively efficient antenna design with a gain of -1.5 dBi in each device, the maximum H-Block power at the A or B Block receiver drops to -16 dBm. While the output power of the H Block device can be as high as +25 dBm, this is seldom the case, as most devices operate at a nominal maximum power of +22 to +23 dBm, dropping the H Block power at 1 meter still further to between -18 and -19 dBm. Additional losses, such as those attributable to the presence of the user's hand, holding the device to the head, etc., would lower this H Block power level still further. For the time being, we will use the -13 dBm number as a starting point for H-Block power at the A or B Block receiver in this analysis.

The results presented in Tables 1.1 through 6.2 above may contain the entry "BER Not Met" in some cells. This entry indicates that the BER criteria could not be met at the beginning of the test with no impairment present. This entry is common in UMTS test cases where *DPCH_Ec/Ior* is -16.6 dB and *Ior* is set to a value within 1 or 3 dB of the UE REFSENS. This behavior is expected, because the UE REFSENS is based on a *DPCH_Ec/Ior* of -10.3 dB.

For Out of Band Emissions (OOBE), the industry seems to be coalescing around an H Block emissions limit of -66 dBm/MHz in the 1930-2000 MHz range (-126 dBm/Hz). Going back to our 38 dB path loss assumption, this places the inband noise level at (-126 dBm/Hz + (– 38 dB)) =-164 dBm/Hz. This level is 10 dB above the thermal noise floor when the devices are 1 meter apart. Like the H Block power calculations, OOBE power is also further reduced by antenna losses, so realistically most devices will see about -167 dBm/Hz or less OOBE from a compliant H Block UE. But for this paper, we will use the -164 dBm/Hz worst-case value.

Receiver Blocking/Overload

GSM: When tested at a serving cell power level 3 dB above the 3GPP-specified reference sensitivity in the 1900 MHz band, GSM devices were susceptible to H Block interference at levels as low as -17 dBm/5 MHz as shown in Table 2.1.

When comparing measured blocking performance to industry standards, both GSM devices met their conformance specification, which calls for the device to display no significant receiver performance impairment up to an interfering power level of -26 dBm[2] (see 3GPP TS 45.005, Clause 5.1, Table 5.1-2a). Conformance with this requirement is based on a serving cell power of 3GPP REFSENS + 3 dB and an "in-band" interferer at an offset of 3 MHz ≤ |f-fo |. Under these conditions, both GSM devices out-performed the 3GPP blocking specification by at least 9 dB. In spite of outperforming the 3GPP specification, our results indicate that GSM may prove to be the airlink most susceptible to blocking and overload interference from a nearby H Block uplink, primarily because even under these highly favorable serving cell power conditions, the GSM devices met the 3GPP conformance specification with the least margin of any tested airlink.

UMTS: All UMTS devices tested show much better immunity to receiver blocking and overload than GSM if the downlink *DPCH_Ec/Ior* is -10.3 dB (the value used for almost all 3GPP conformance tests). In cases where the serving cell *DPCH_Ec/Ior* was low (e.g. -16.6 dB) and the performance point was based on the 3GPP REFSENS, the UMTS receiver's susceptibility to H Block interference increased approximately the same amount as the *DPCH_Ec/Ior* was decreased from -10.3 dB. For all UMTS devices it was never worse than -18 dBm (see Table 2.2). It's also interesting to note that UMTS devices performed exceedingly well with a *DPCH_Ec/Ior* of -10.3 dB and a serving cell *Ior* only 3 dB above the device's actual reference sensitivity (as shown in Tables 1.1 and 1.3). In fact, the H Block interference necessary to impair the UE receiver in UMTS Device C was nearly the same between the worst-case and the typical design test condition. The extremely poor performance documented for a *DPCH_Ec/Ior* of -16.6 dB when testing at serving cell power levels either 1 or 3 dB above the UE REFSENS is to be expected, since REFSENS is measured with a *DPCH_Ec/Ior* of -10.3 dB and lowering the *DPCH_Ec/Ior* will take the receiver's operating point below the device's reference sensitivity. Please note that in Table 1.1, UMTS Device C displayed significant susceptibility to an H Block uplink at very low levels when the serving cell power was set to 1 dB above the device's REFSENS and *DPCH_Ec/Ior* was set to -10.3 dB. These results are to be expected, as the associated serving-cell power level in this case is very close to the device's reference sensitivity, and therefore the BER behavior is highly non-linear.

When comparing measured blocking performance to industry standards for UMTS devices, the 3GPP TS 25.101 core specification calls for a UMTS device to tolerate a UMTS interferer at a power level of -44 dBm/3.84 MHz. Conformance with this requirement must be met when the serving cell power is set to 3GPP REFSENS +3 dB, *DPCH_Ec/Ior* is set to -10.3 dB and the carrier frequency of the interferer is offset by 15 MHz. We executed UMTS blocking tests at 3GPP REFSENS +3 dB as well as UE REFSENS + 1 dB and UE REFSENS +3 dB. In all cases except one, our results indicate that UMTS devices outperformed the 3GPP blocking specifications by at least 26 dB. The only exception was UMTS Device C at UE REFSENS

[2] GSM blocking performance called for in the 3GPP 45.005 core specification is based on a CW (continuous wave) interferer. In this test we utilized an LTE signal as the interferer, which consists of a suite of modulated tones. Thus, the test environment is not exactly the same as that assumed by the 3GPP core and test specifications, however, we believe that this difference in the type of interferer is not relevant to the validity of our test results.

+1 dB, which failed to meet the 3GPP blocking specification. However, as described in Footnote 1, this appears to be related to measurement uncertainty and the receiver's non-linear behavior at UE REFSENS +1 dB, which represents a test scenario well outside the 3GPP specifications. Also, we should note that the 3GPP blocking test is based in the presence of a UMTS interferer, but our tests were executed using a 5 MHz LTE interferer. We believe that this difference in the type of interferer is not relevant to the validity of our test results.

LTE: The LTE device displayed excellent immunity to overload/blocking under worst case and typical design test conditions. In both test scenarios, the LTE device could tolerate essentially the same H Block power as a UMTS device under similar operating conditions.

When comparing measured blocking performance to industry standards for LTE devices, the 3GPP 36.101 core specification calls for an LTE device to tolerate a blocking interferer power level of -44 dBm/5 MHz. This performance must be met when the serving cell power is set to 3GPP REFSENS +6 dB and the carrier frequency of the interferer is within15 MHz of the carrier frequency of the serving cell situated at the low end of the desired band (see 3GPP TS 36.101, Clause 7.6, Table 7.6.1.1-2). Under all test conditions (i.e. 3GPP REFSENS + 3 dB, UE REFSENS +1 dB, UE REFSENS + 3 dB) we found that the LTE device outperformed the 3GPP blocking specification by at least 30 dB with an H Block interferer on 1917.5 MHz and a B Block downlink on 1932.5 MHz (15 MHz offset).

Receiver Overload/Blocking Summary: Measurements show that UMTS and LTE UEs displayed very good immunity to H Block interference, with the exception of UMTS tests executed at 1 dB above the UE REFSENS, where non-linearity in the UE receiver can cause the BER to be exceptionally high for an interfering power level that's unusually low. It appears that an H Block device operating at full power 1 meter away from a PCS A Block device will not create significant receiver impairment to UMTS and LTE. GSM devices display noticeable performance impairment when the H block device transmits at a power level within 2 dB from its nominal maximum output power or 23 dBm, This result indicates that there is minimal coexistence latitude for GSM devices in the vicinity of an H Block device..

Receiver IMD

UMTS: Like the receiver overload/blocking results described in the previous subsection, UMTS devices displayed excellent rejection of the H Block interferer, even under worst-case conditions where *Ior* was either 1 or 3 dB above the device's REFSENS (provided the *DPCH_Ec/Ior* was -10.3 dB) with the exception of Device A in Table 3.3. This device has excellent sensitivity, and as such was able to meet the 3GPP UMTS BER (0.1 %) when the serving cell power was set to UE REFSENS +3 dB and *DPCH_Ec/Ior* was -16.6 dB. However, when the interferer was added, we see the same non-linear behavior as described in Footnote 1, and these results can be considered anomalous. Overall, it's interesting to note that the H Block power levels associated with the onset of receiver impairment are essentially the same regardless of whether the serving-cell *Ior* was set to 1 dB above UE REFSENS, 3 dB above UE REFSENS, or 3 dB above 3GPP REFSENS. This implies that the impairment mechanism is probably wideband noise from the H Block signal generator rather than IMD generated within the device.

When comparing measured IMD performance to industry standards for UMTS devices, the 3GPP TS 25.101 core specification calls for a UMTS device to tolerate a UMTS interferer power level of -46 dBm/3.84 MHz. This performance must be met when the serving cell power is 3 dB above the 3GPP REFSENS, *DPCH_Ec/Ior* is -10.3 dB, and the interfering signal is offset by 20 MHz. We executed IMD tests with the UMTS serving cell on 1957.5 MHz and the interfering LTE uplink on 1917.5 MHz (testing for an internally-generated third-order mix (2*1917.5 MHz -1877.5 MHz=1957.5 MHz), resulting in an interferer offset of 40 MHz. Thus, no direct relationship exists between our test conditions and the 3GPP IMD specification for UMTS devices. However, even in this modified test environment, UMTS devices outperformed the 3GPP IMD specification by at least 29 dB, with the exception of UMTS Device A as noted above.

LTE: Receiver IMD performance of the LTE device was noticeably better than a UMTS device operating under similar serving cell conditions. Even at a serving cell power 1 dB above the device's reference sensitivity, no impairment was noted until the H Block signal reached -3 dBm, which implies that other test platform limitations were probably creating this impairment as opposed to actual IMD generated within the device.

When comparing measured IMD performance to industry standards for LTE devices, the 3GPP 36.101 core specification calls for an LTE device to tolerate a interferer power level of -46 dBm/5 MHz. This performance must be met when the serving cell power is 6 dB above the 3GPP REFSENS and the interfering signal is offset by 20 MHz. We executed IMD tests with the LTE serving cell on 1957.5 MHz and the interfering LTE uplink on 1917.5 MHz (testing for an internally-generated third-order mix (2*1917.5 MHz -1877.5 MHz=1957.5 MHz), resulting in an interferer offset of 40 MHz. Thus, no direct relationship exists between our test conditions and the 3GPP IMD specification for LTE devices. However, even in this modified test environment, LTE devices outperformed the 3GPP IMD specification by at least 38 dB.

Summary: The H Block power required to cause receiver impairment in this test scenario was high enough to indicate that IMD is unlikely to create a significant impairment to B Block UMTS and LTE devices when operating in close proximity to an H Block device.

Receiver Impairment due to H Block Transmitter OOBE

GSM: The two GSM devices tested for susceptibility to H-Block OOBE displayed receiver performance impairment at very low on-channel noise levels when tested under worst-case conditions at the UE REFSENS +1 dB or UE REFSENS +3 dB operating points. As shown in Tables 5.1 and 5.4, on-channel noise levels at or below the thermal noise floor caused receiver impairment at UE REFSENS +1 dB.

UMTS: When executing OOBE susceptibility tests against UMTS devices where the downlink power was 3 dB above the 3GPP REFSENS and the *DPCH_Ec/Ior* was -10.3 dB, all tested devices required an on-channel noise power of at least -155 dBm/Hz, 9 dB higher than the highest expected noise power from an H Block device 1 meter away as defined by the prerequisites in this sub-section. If the *DPCH_Ec/Ior* is reduced about 6 dB to -16.6 dB, the UMTS device's susceptibility to on-channel noise increases considerably to -166 dBm/Hz. Thus, it appears that cell loading could have a significant impact on the ability of a UMTS device to tolerate OOBE from an H Block device. However, the values in Table 6.2 do not take into account other H Block attenuation contributions such as antenna gain and body loss. When tested at levels just above the device's actual reference sensitivity (UE REFSENS +1 dB or UE REFSENS +3 dB), the UMTS devices displayed a susceptibility to OOBE noise similar to the 3GPP REFSENS +3 dB performance when the cell is heavily loaded. Even under these less than optimal serving cell power conditions, the UMTS devices displayed much less susceptibility to OOBE from an H Block device than GSM devices.

LTE: The LTE device tested (see Table 6.3) shows excellent rejection of noise due to H Block OOBE. This test was executed at a serving cell power level 3 dB above the 3GPP REFSENS, and at levels just above the device's actual reference sensitivity (UE REFSENS +1 dB and UE REFSENS +3dB). Under these worst-case conditions (as shown in Tables 5.3 and 5.6), the LTE device displayed susceptibility to OOBE noise similar to that of the UMTS devices under lightly-loaded channel conditions.

Summary: The proposed OOBE limit of -66 dBm/MHz (-126 dBm/Hz) appears to be sufficient to protect victim A Block UMTS and LTE devices 1 meter away from an H Block device. Our test results indicate that GSM devices appear to be significantly more sensitive to H Block OOBE, and at 1 meter separation will display very little latitude for coexistence with a nearby H Block device.